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Checking the Numbers for the Labyrinths Shown in the SSC Conceptual Design*

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In this note I review the designs for access labyrinths presently shown in the Conceptual Design Report (SSC-SR-2020) to see if they are reasonable for radiation protection purposes. This matter was previously studied two years ago in a Fermilab TM (Co85a). The methods used are based upon scaling the results of calculations done by Gollon and Awschalom (Go71). Confidence in the results has been fortified by a successful experimental test (Co85b). The Conceptual Design Report shows two types of access labyrinths which are significantly different. The first type is that at a Sector Service Area while the second is that provided for personnel entry to the Interaction Regions. Relevant figures from that document are presented below.

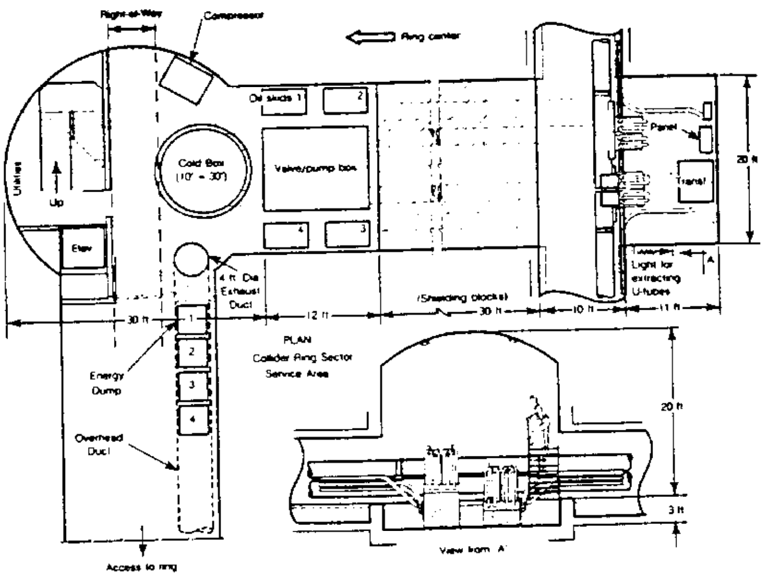


Figure 6.6-4. Collider Ring Access Shaft plan view.

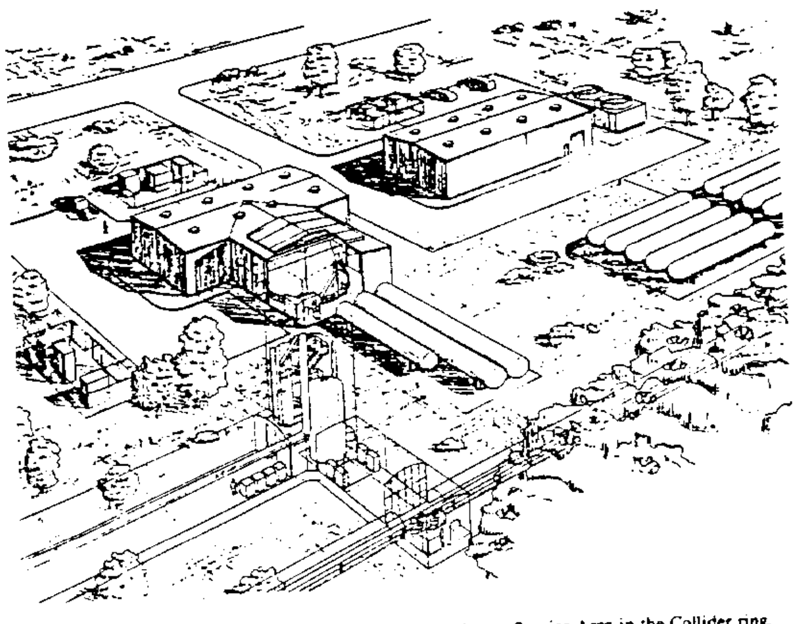


Figure 6.6-5. Perspective view of the Sector Service Area in the Collider ring.

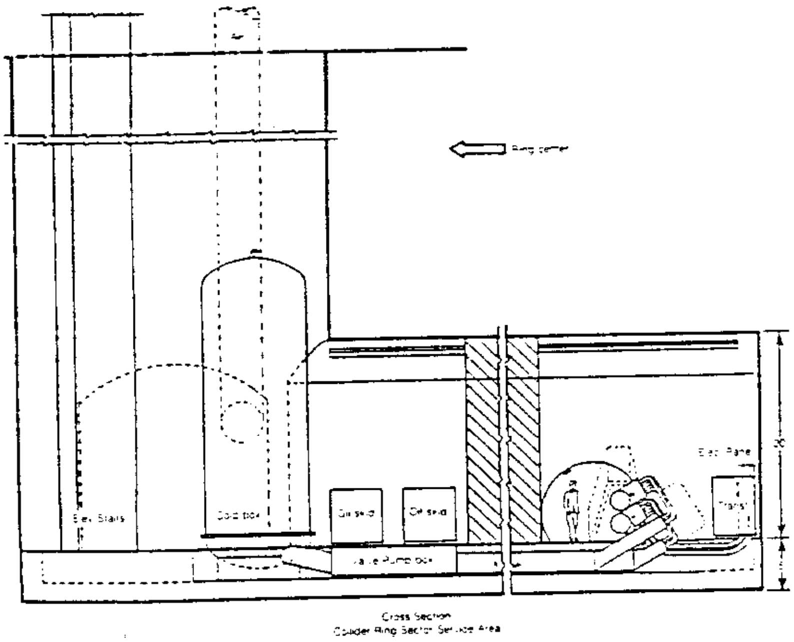


Figure 6.6-3. Collider Ring Sector Service Area, Access-Shaft and Tunnel Intercept seen in cross section.

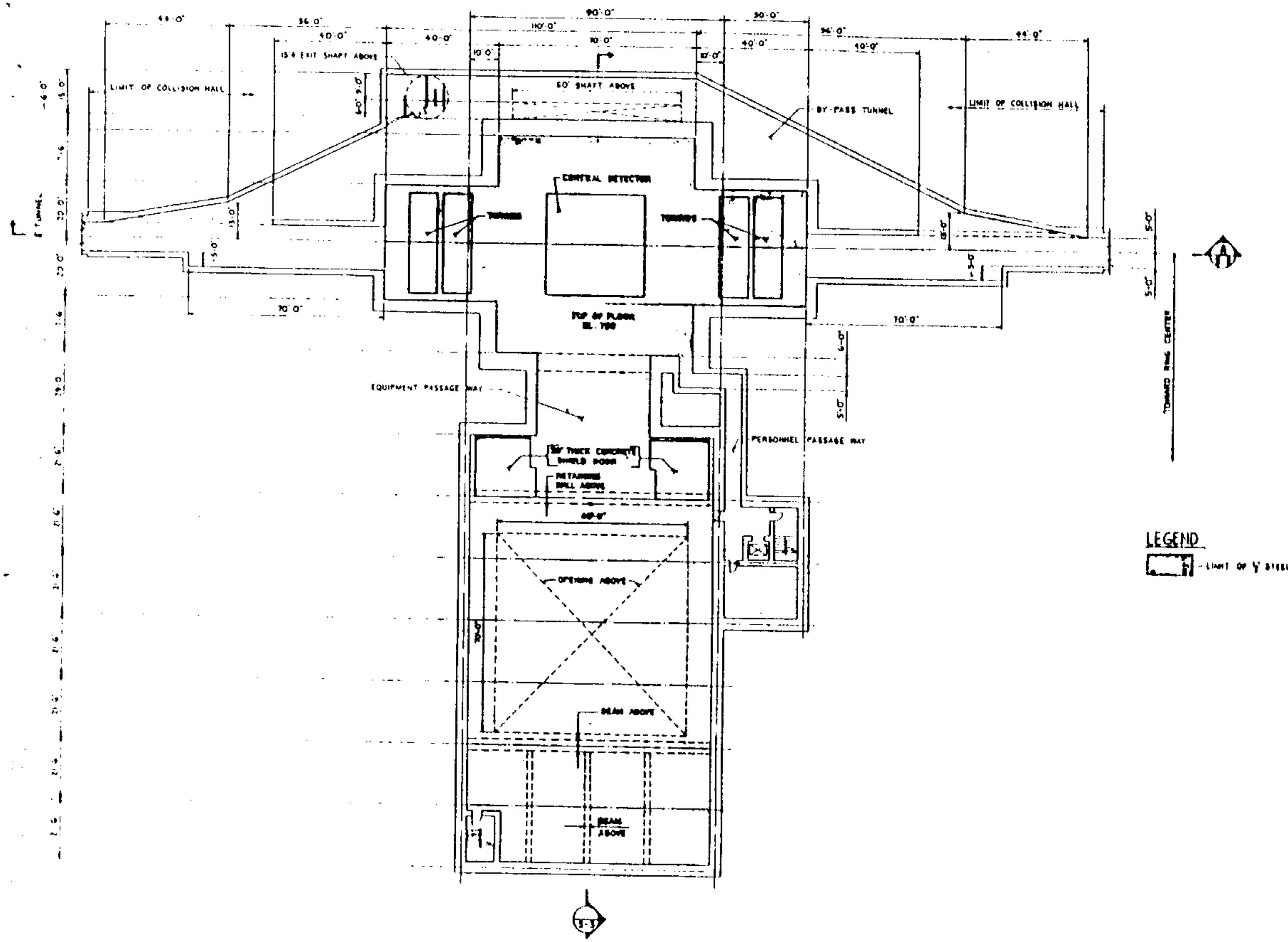


Figure 6.7-1. Plan View of Type A Interaction Region showing collision hall, access way, shield doors, assembly area and Staging Building.

The principal result obtained by Gollon and Awschalom was a set of calculated attenuation curves which give relative values of neutron fluence (approximately the same for the dose equivalent), at given locations in the maze. It was concluded by these workers that the attenuation would go according to linear dimensions scaled to $(A)^{1/2}$ where A is the cross sectional area of the passageway. In other words, $L/(A)^{1/2}$ provides the scaling "units" which can be used with "universal" attenuation curves. Figures from their publication which are relevant to the present discussion are copied here:

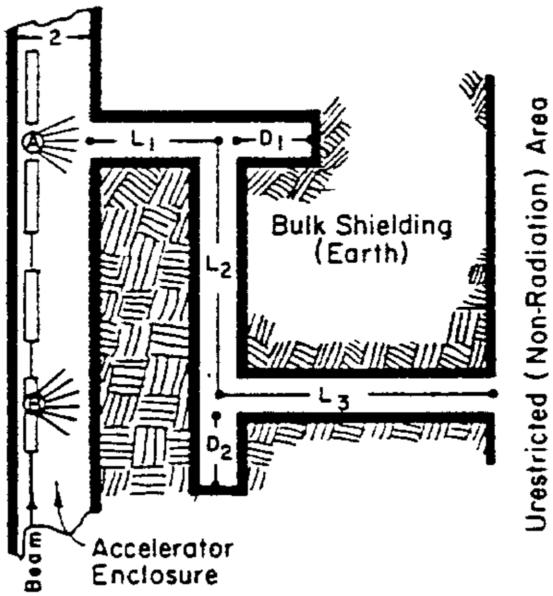


Figure 1. A typical multi-leg penetration used in neutron flux attenuation calculations.

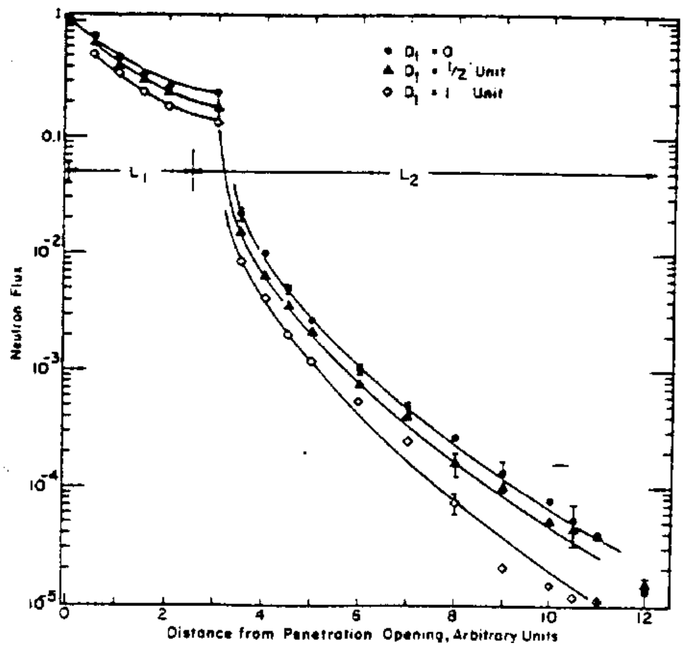
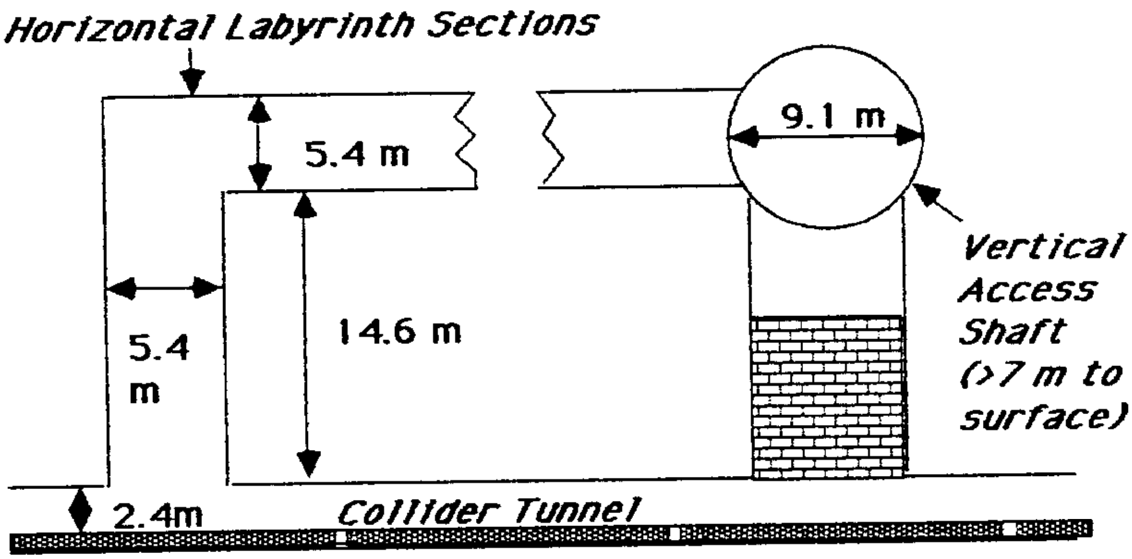


Figure 6. Neutron flux in a two-legged labyrinth with a cul-de-sac of varying depth at the end of the first leg of length $L_1 = 2.5 \sqrt{A}$

First consider the ring access shaft. I could not find this structure shown in its entirety in the report so I have had to guess what it might look like based upon the written description. The following sketch is an expression of my interpretation. It is to be noted that the length of the second "leg" has not been specified so I will end this discussion by making a suggestion.



First it is necessary to make some estimate of the beam loss conditions and the consequent allowable dose equivalent to a person standing at the top of the access shaft. To do this I have assumed that even under "worst case" scenarios, it is unlikely that more than 10^{12} protons per meter over about 100m of tunnel would likely be lost in any given year. Since these access points are widely distributed in the ring, I believe it would be prudent to limit the dose equivalent in such a place to, say, 10 mrem. From Van Ginneken's recent extensive set of calculations (Va87), figure 66, it is clear that a loss of beam produces a maximum of 2 $\times 10^{-6}$ mrem/proton at the tunnel wall having an inner radius of 1.2 m. As seen above, the accessways being proposed enter the tunnel from the side <u>away</u> from the magnets and hence the "mouth" of the labyrinth views any possible loss point at a distance of about 2.4 m. Also from Van Ginneken's work, for a point loss, only about 10 m of tunnel wall sees more than half of the maximum dose equivalent. For the assumed loss condition, the dose at the mouth of the labyrinth would simply be given (including a conservative "line source" geometry scaling factor) by:

$$(1.2/2.4) \times (2 \times 10^{-6}\ \text{mrem/proton}) \times (10^{12}\text{proton/m}) \times 10\ \text{m} = 10^{7}\ \text{mrem}.$$

Thus the desired attenuation factor is $10/(1 \times 10^{7}) = 1 \times 10^{-6}$.

The **first leg** has a cross sectional area of about $5.4 \times 5.4\ \text{m}^2$. Its length, according to my interpretation of the figures, is 17.3 m so that it is 3.2 "units" long. Consider the source to be a "line source", Figure 6 of (Go71) gives an attenuation factor of **0.25** for this leg.

Sections after the innermost were found by Gollon and Awschalom to be similarly effective for rectilinear labyrinths. Since the length of the second is presently unspecified, consider the **third section**. This leg, the vertical shaft, has a cross sectional area of 65 m^2 if one ignores any concrete structures which might be installed (likely to be thin and of limited shielding effectiveness). This means that a "unit" = 8 m. The length of this section, taking the shield over the ring to be the minimal 7 m, is only about 1.2 "units". Still, going around corners always helps and this leg, by the figure from (Go71) attenuates by a factor of **0.06**.

The **second leg** must provide the remaining attenaution factor of **6.6×10^{-5}**. From the figure, this will occur after 10 "units", or **54 m**. These passageways can be made considerably shorter by making them smaller in cross section according to the scaling rules of Gollon.

For a "Type A" Interaction Regions (both types being nearly the same for purposes of this discussion) the same procedure may be used. It should be noted that the "mouth" is 37.5' (11.4 m) from the nearest point to the beamline and 48' (14.6 m) from the intended vertex of the collisions. Having no better information, I have estimated that the cross-sectional dimensions of these passageways (which appear to be designed purely for people) to be 5' X 8' which implies a cross sectional area of 40 ft^2. Thus $(A)^{1/2}$ = 6.3 ft (1.9 m). Thus the **first leg** is about 1.4 "units" long. From Fig. 6 of Gollon's work, it is conservative to take the attenuation factor of this section to be **0.45**. Continuing with the **second leg,** it is about 17 ft (5.2 m) long and hence approximately 2.7 "units". Thus the figure gives an approximate attenuation factor of **8×10^{-3}** for the second leg. Going now to the **third leg** we find it to be 42 ft (12.8 m) and hence 6.7 "units". The resulting attenuation factor may be read off as **4×10^{-4}**. Thus the total attenuation for the three-legged labyrinth is **1.4×10^{-6}**.

For this passageway there are two possible types of beam loss to consider. The first is accidental loss upon the beam pipe, a "fixed target" loss. To get an estimate of the source term again consult (Va87). In Figure 70 at a radius of 1.2 m a result of 2×10^{-7} mrem/proton is seen to be a maximum for a loss on a **bare beam pipe** of 20 TeV protons. If one supposes the collision hall to be empty, the loss of 1.3×10^{14} protons directly opposite the labyrinth would, invoking a 1/r dependence, produce a dose equivalent of

$$(1.2/11.4) \times (2 \times 10^{-7}) \times (1.3 \times 10^{14}) = 2.7 \times 10^{6} \text{ mrem}$$

at the mouth of the labyrinth. Multiplying by the attenuation factor determined above would result in a dose equivalent of **3.8 mrem.** It is clearly unlikely that the interaction regions would ever be truly empty, or just contain a bare beam pipe. However, it is more likely that massive components would be in place which would reduce this dose by self-shielding. At any rate, such a catastrophic beam loss is unlikely to occurr even as frequently as annually. This dose equivalent is therefore acceptable for such a controlled laboratory area.

The other type of loss is the steady loss due to the inelastic collisions of the 20 TeV protons. From Figure 144 of the work of Van Ginneken cited above, one finds a dose of 5×10^{-9} mrem/inelastic collision at a radius of 10 m from the vertex. This estimate is <u>highly</u> conservative due to the forward propagation of the particles from these collisions. Nevertheless, allowing for vertex to be in the <u>wrong</u> location (a highly surprising event to the accelerator physicists!) this is a somewhat useful <u>maximum</u> value. If we have, at $\mathbf{L} = 10^{33}$, 9×10^{7}collisions s^{-1} or 3×10^{11} h^{-1}, one would have a maximum dose rate at 10 meters of 1500 mrem h^{-1}. Multiplying by the attenuation calculated above results in a dose equivalent rate of **2.1 μrem h^{-1}** at the worst point. This is an entirely acceptable value.

Thus it appears that the design of the access penetrations is appropriate

References:

Co85a J. D. Cossairt, Fermilab TM-1307 (SSC-N-10) (1985).

Co85b J. D. Cossairt, J. G. Couch, A. J. Elwyn, and W. S. Freeman, Health Phys. 49 (1985) 907.

Go71 P. J. Gollon and M. Awschalom, IEEE Trans. Nucl. Sci., NS-18 (1971) 741.

Va87 A. Van Ginneken, P. Yurista, and C. Yamaguchi, Fermilab FN-447 (SSC-106)(1987).